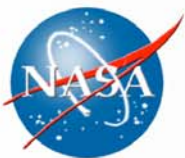




Supersonics—Airport Noise

At this, the first year-end meeting of the Fundamental Aeronautics Program, an overview of the Airport Noise discipline of the Supersonics Project leads the presentation of technical plans and achievements in this area of the Project. The overview starts by defining the Technical Challenges targeted by Airport Noise efforts, and the Approaches planned to meet these challenges. These are fleshed out in Elements, namely Prediction, Diagnostics, and Engineering, and broken down into Tasks. The Tasks level is where individual researchers' work is defined and from whence the technical presentations to follow this presentation come. This overview also presents the Milestones accomplished to date and to be completed in the next year. Finally, the NASA Research Announcement cooperative agreement activities are covered and tied to the Tasks and Milestones.



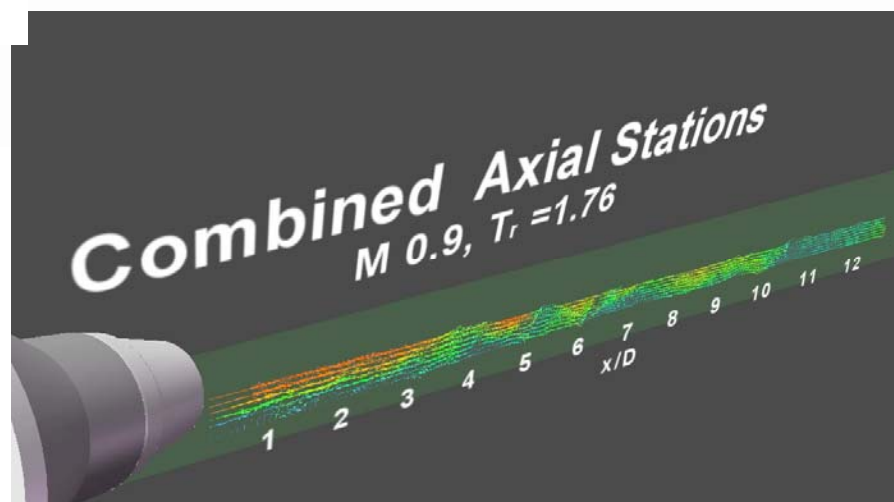
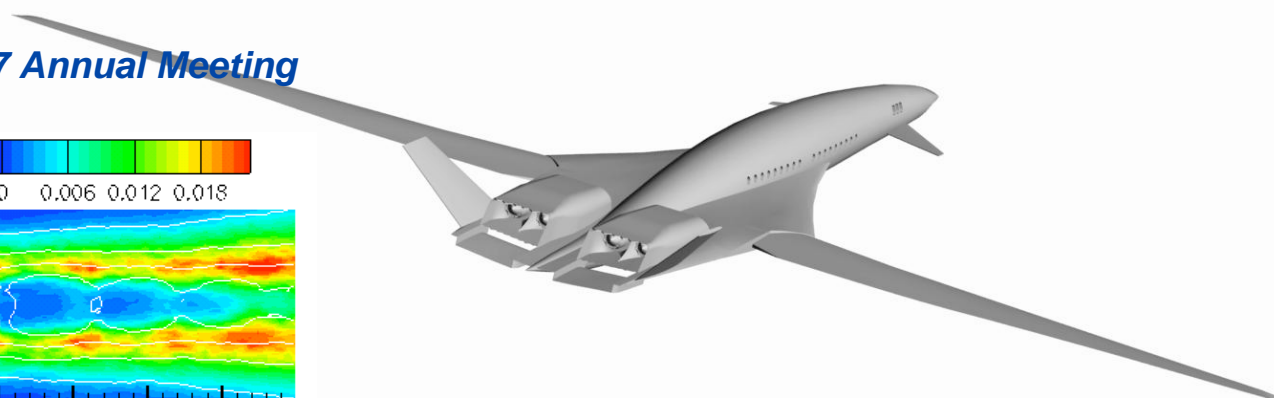
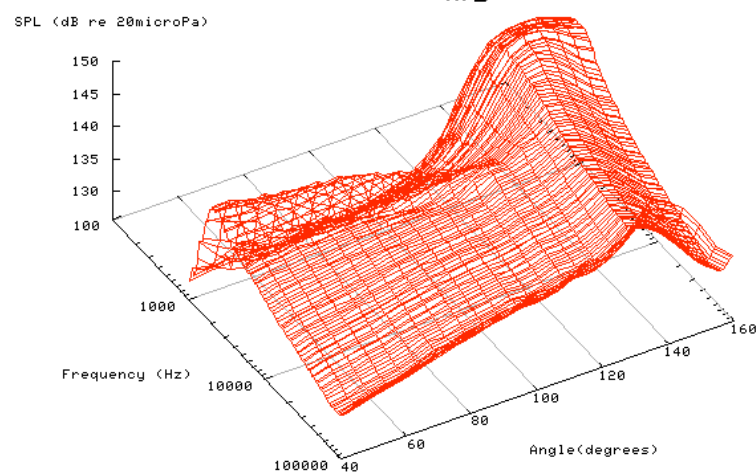
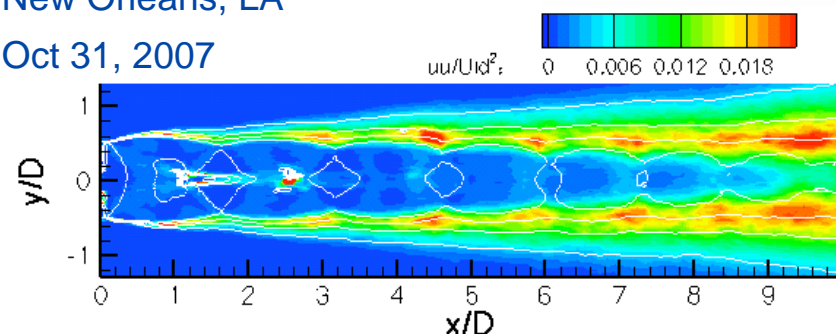
Supersonics—Airport Noise

James Bridges, API

Fundamental Aeronautics 2007 Annual Meeting

New Orleans, LA

Oct 31, 2007





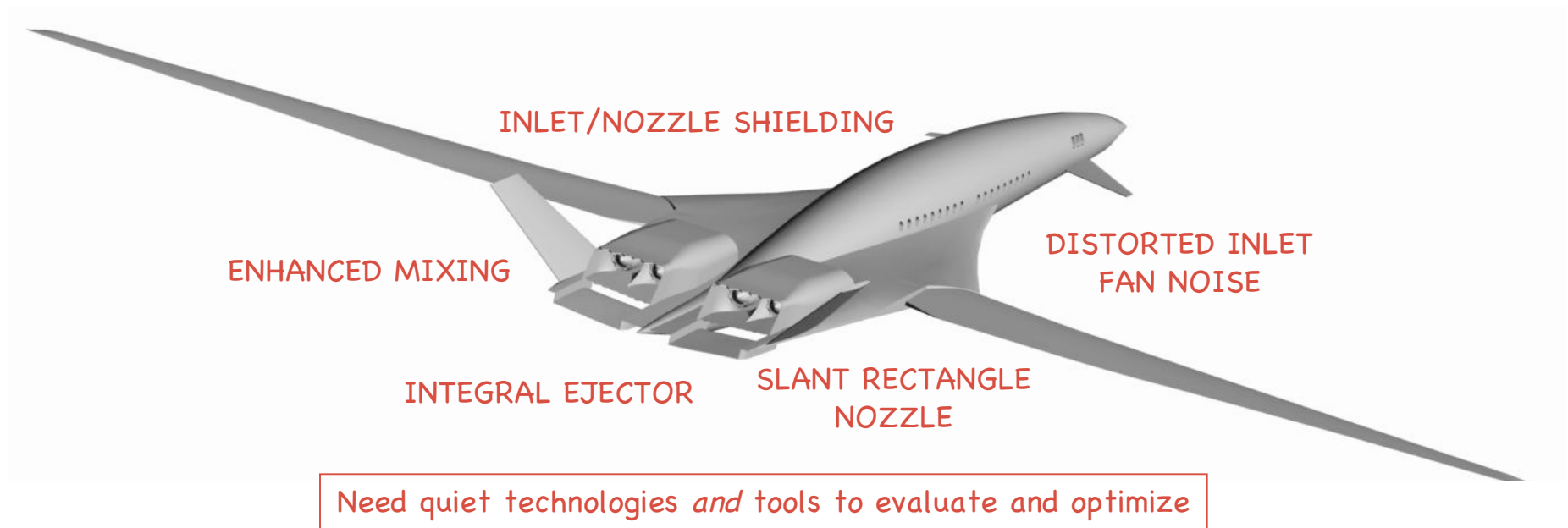
Presentation Outline

- Technical Challenge
- Technical Approaches
 - Elements/Tasks
- NRAs
- FY08 Task Highlights



Technical Challenge

- Enable vehicles capable of economical supersonic flight to be acoustically compatible with existing fleet around airports.
- Envision **noise reduction technologies** which break current overall noise trends of noise vs specific thrust.
- Create design and analysis **tools** to evaluate and optimize noise along with other aircraft performance measures.





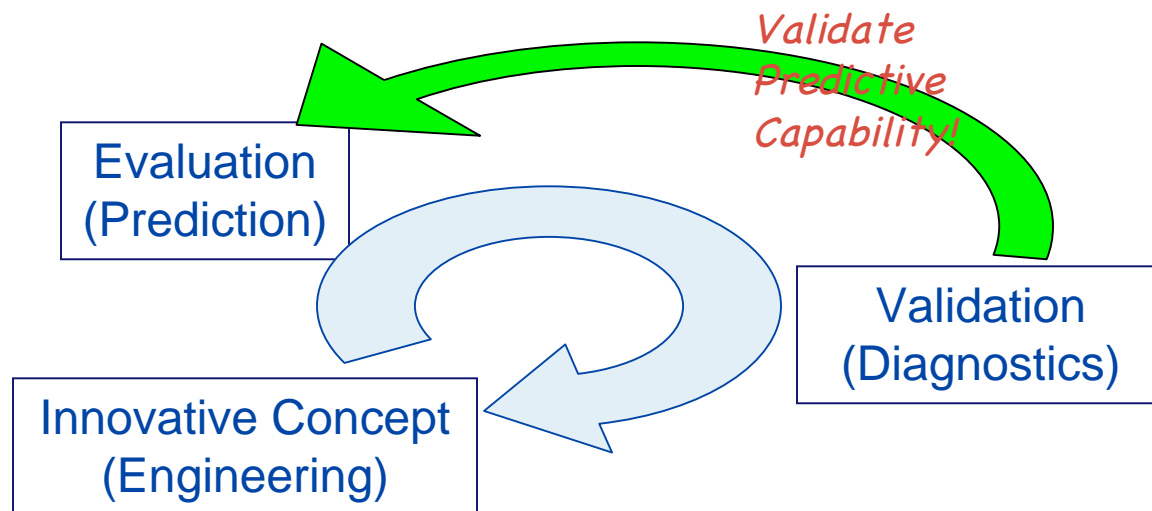
Technical Challenge—Response

- Strong emphasis on reducing uncertainty of, and increasing insight from noise concept evaluation
- Jet noise remains highest barrier for supersonic aircraft near airports.
- Heavy reliance on Subsonic Fixed Wing Project for Airframe, Turbomachinery noise technology.



Technical Approach

- Airport Noise Elements:
 - 07.02 Prediction
 - 07.03 Diagnostics
 - 07.04 Engineering





07.02 Prediction Element

- **07.02.01** Assessment of Supersonic Noise Prediction Tools
 - Empirical codes
 - Statistical codes
 - Time-resolved codes
- **07.02.02** Time-resolved CFD/CAA for Jet Aeroacoustics
 - LES for non-compact sources
 - LEE for complex propagation in shocked flow
- **07.02.03** Statistical Modeling of Supersonic Jet Noise
 - High temperature 3D jet mixing noise
 - **Broadband shock noise*** in complex 3D flows
 - Non-compact source/Mach wave emission in high speed flows

Key Milestones:

SUP.07.02.001 Assess Empirical Supersonic Noise Prediction Tools **12/2007**

SUP.07.02.011 Develop Improved Statistical Model for Broadband Shock Noise **9/2008**

SUP.07.02.012 Broadband Shock Noise for 3D Dual-flow Jets **12/2010**

SUP.07.02.013 Develop Statistical Model for Mach Wave Emission **9/2011**



07.03 Diagnostics Element

- **07.03.01** Turbulence Statistics for Noise Prediction Codes
 - Space-time correlations of velocity, temperature
 - **Shock-turbulence interaction***
 - Instability wave characterization
- **07.03.02** Supersonic Aeroacoustic Database for Dual Flow Jets
 - Flow: Plume velocity, temperature, shock locations
 - Noise: Far-field spectral directivity, source distribution
 - Variable Geometry (aspect ratio, improperly expanded)
- **07.03.03** Phased Array Diagnostics of Hot Supersonic Jets
 - Conventional and unconventional beamforming
 - Simultaneous flow and acoustic array measurements

Key Milestones:

SUP.07.03.001 Velocity Spectra Measured in Hot Supersonic Jets **12/2007**

SUP.07.03.003 Measure Spectra of Unsteady Temperature in Hot Supersonic Jet **12/2010**

SUP.07.03.006 Supersonic Aeroacoustic Database of Flow+Noise of Axisymmetric Jets **12/2008**

SUP.07.03.008 Supersonic Aeroacoustic Database of Flow+Noise of 3D Dual-Flow Supersonic Jets **12/2010**



07.04 Engineering Element

- **07.04.01 Shock Modifications for Reduced Broadband Shock Noise**
 - **Slot injection at nozzle lip***
- **07.04.02 Offset Stream Nozzles to Reduce High-Speed Noise**
 - Modification of non-compact source/instability wave
- **07.04.04 Iconic Supersonic Vehicle**
 - Cross-discipline, trans-resolution design exercise
- **07.04.05 Unsteady Actuator for Time-Dependent Jet Control**
 - LES-optimized temporal control of jet instabilities
 - Medium-scale validation/reality check

Key Milestones:

SUP.07.04.001 Initial Assessment of Slot Injection for Shock Noise Reduction Complete **12/2007**

SUP.07.04.009 Impact of Plasma Actuator on Jet Noise Demo in Small and Medium Scale Rig **6/2009**

SUP.07.04.007 Use Statistical Noise Code to Design Supersonic Nozzle **12/2009**

SUP.07.04.005 Demonstrate Role of Mach Wave Emission Using Offset Stream Jet **12/2010**



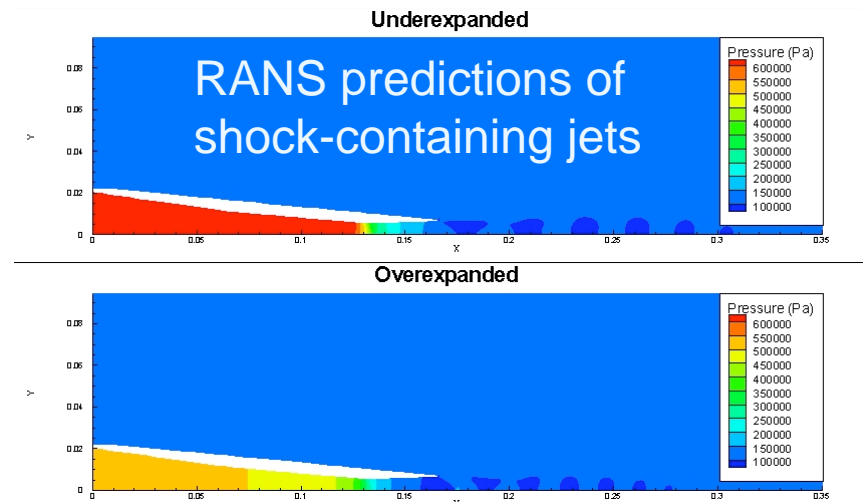
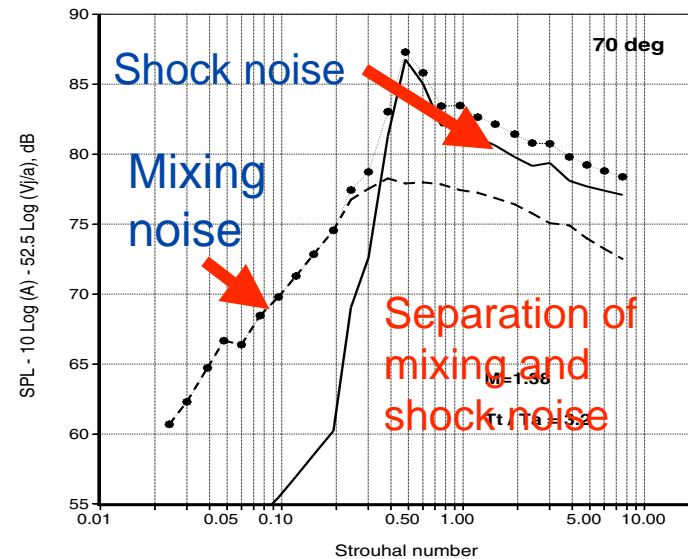
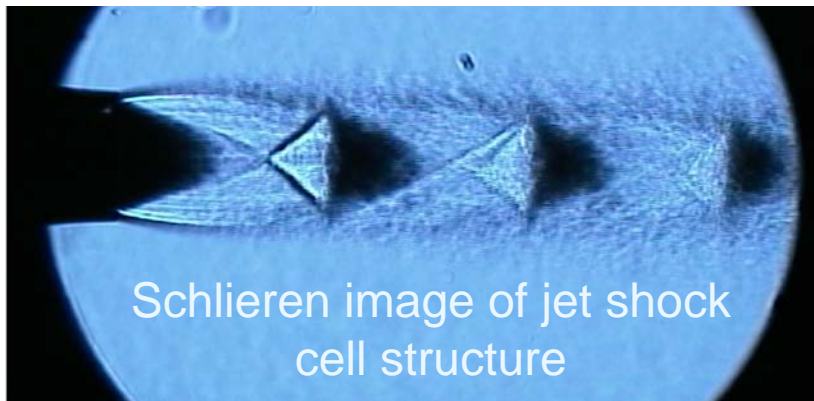
07.66 NRAs

- Round 1 (started Spring 07)
 - A Comprehensive Model for the Prediction of Supersonic Jet Noise, *Penn State University, Boeing Aircraft Co.; Philip Morris, PI*
 - Prediction and modeling of supersonic jet noise using large-eddy simulation, *Stanford U., U. Illinois Urbana-Champaign, Sanjiva Lele, PI*
 - Supersonic Jet Noise Reduction via Reshaping of the Exhaust Plume, *U. of Cal Irvine, Dimitri Papamoschou, PI*
 - Supersonic Jet Noise Suppression Using Plasma Actuators: Coupled Experiments, LES and Adjoint-based Optimization, *Ohio State U., U. Illinois Urbana-Champaign, Mo Samimy, PI*
- Round 3 (to be announced)
 - Subtopic A.3.3: Aeroacoustic Diagnostics for Jet Noise Source Prediction
 - Subtopic A.3.4: High Fidelity Supersonic Propulsion Exhaust System Design and Model for Validation

Prediction and Measurements of Broadband Shock-Associated Noise

PI: Philip J. Morris, Penn State U.

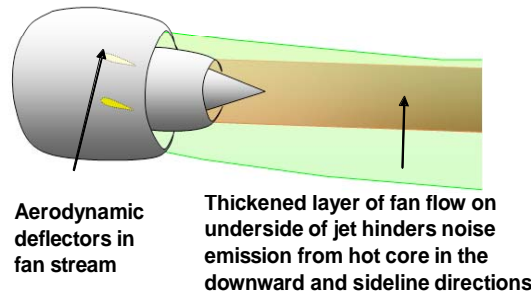
- No method exists to predict broadband shock-associated noise for general jet geometries and conditions
- Acoustics and flow-field measurements to be performed at small and moderate scale
- Steady RANS flow simulation coupled with source modeling based on measured unsteady flow properties will provide noise prediction
- Separation of shock-associated noise from other jet noise sources accomplished using new empirical method
- Close collaboration between Penn State, Boeing and NASA – good progress in all sub-tasks





Supersonic Jet Noise Reduction Via Reshaping Of The Exhaust Plume

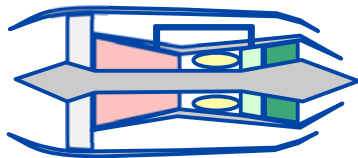
PI: Dimitri Papamoschou / Co-PI: Feng Liu; U. Cal Irvine



OBJECTIVES

- Reduce takeoff noise of supersonic aircraft by asymmetric reshaping of the dual-stream plume from turbofan engines.
- Use deflection of the fan flow to achieve the asymmetric reshaping.
- Optimize the nozzle and deflector designs.
- Understand and model the noise reduction versus changes in the mean flow field.

Takeoff exhaust conditions



Thermodynamic cycle analysis for optimum $M=1.6$ cruise BPR and FPR. Gives exhaust conditions on takeoff.

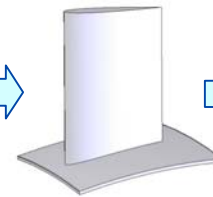
Current status

- Completed cycle analysis.
- Designed and fabricated 2 base nozzles and variety of deflectors.
- Testing 2 base nozzle designs and ~10 deflector arrangements.
- Estimated EPNL reductions up to 4.5 dB.

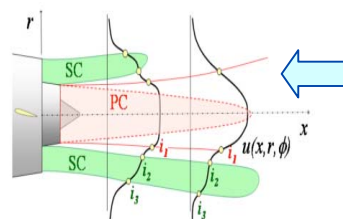
Nozzle and deflector optimization approach



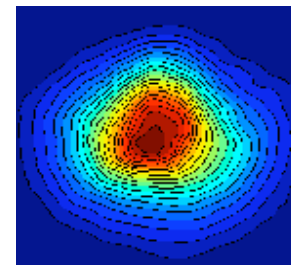
Base nozzle design and fabrication (BPR~2.5)



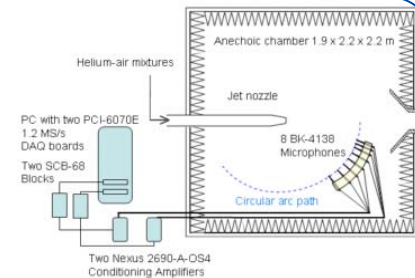
Deflector design, microfab, and arrangement



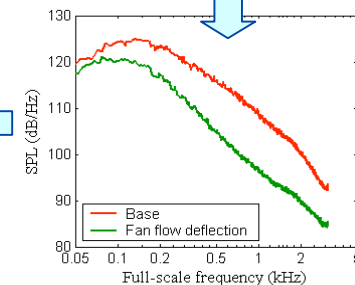
Analysis of velocity field



Mean flow distortion data



Acoustic and mean flow testing



Acoustic data

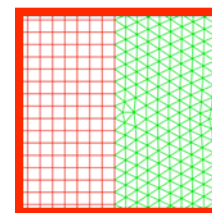
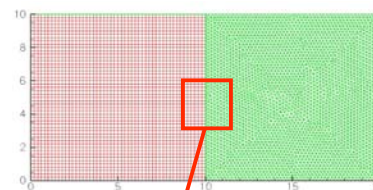
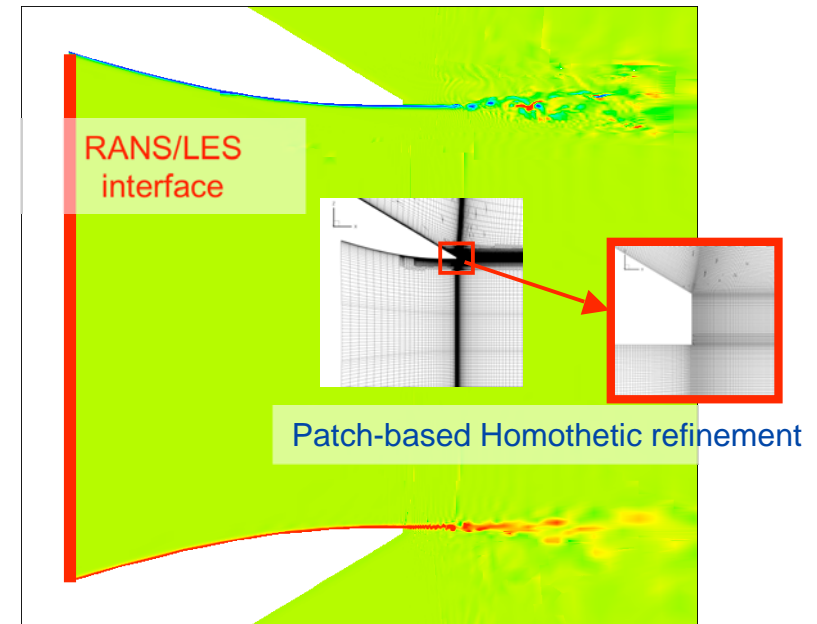


Supersonic Jet Noise using LES

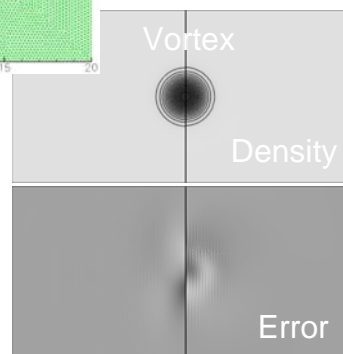
PI: Sanjiva Lele, CoPI Parviz Moin, Stanford University

- **Year 1:** Develop hybrid URANS-LES for simulations of supersonic jets with detailed nozzle geometry.
 - Develop unstructured mesh compressible LES solver. *Version with explicit time advancement completed, implicit version in progress.*
 - Shock-capturing in unstructured mesh solver. *Algorithm selected, implementation to begin.*
 - URANS-LES coupling. *Incompressible unstructured mesh LES/URANS coupling done, compressible LES-URANS coupling in progress.*
 - Ffowcs Williams-Hawkings far-field noise solver. *Tests with jet instability wave noise completed, implementation with full LES in progress.*
- **Year 2:** Validation of hybrid jet LES for simple nozzles with detailed comparisons with NASA-Glenn laboratory data.
- **Year 3-4:** Simulation of supersonic jets from complex nozzles and validation.

Coarse Incompressible LES for grid requirements



Code Coupling



- Compressible multi-code coupling implemented through CHIMPS
- Grid convergence for analytic vortex across interface



Supersonic Jet Noise Suppression Using Plasma Actuators: Coupled Experiments, LES and Adjoint-based Optimization

PI: Mo Samimy (OSU), Co-PIs: Igor Adamovich (OSU); Jonathan Freund and Daniel Bodony (UIUC)

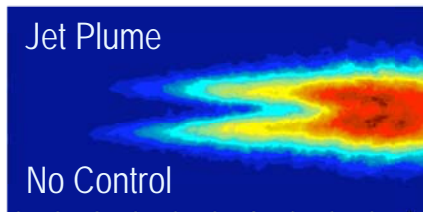
Objective: To use interdisciplinary experimental and computation work

- to extend the application of plasma actuators to supersonic jet noise mitigation
- to demonstrate scalability by implementation at NASA Jet Rig

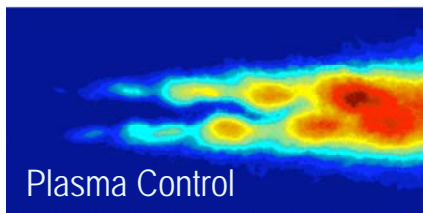
Year One Accomplishments

- Developed a new energy-efficient and lightweight prototype power supply
- Preliminary results show successful application of plasma actuators for noise mitigation in supersonic jets
- Complex geometry code with DNS-like fidelity is up and running well
- LES implemented and being tested
- Actuator model implemented in auxiliary simple-geometry DNS code—coupling with adjoint method and matching the experimental geometry

Single-Frequency
Pulsed Plasma
Flow Control
at $M_j=1.3$

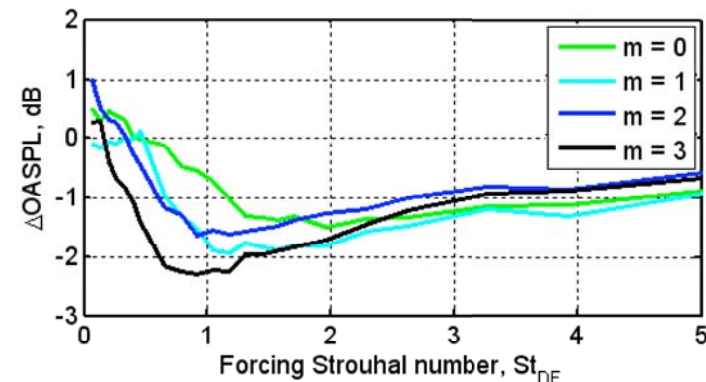


No Control



Plasma Control

Produced
Noise Reduction
...before
optimization!





Sample of Upcoming Tasks in FY08

- Complete development of broadband shock noise code; commence assessment suite.
- Release code base for systematic study of robustness in jet LES.
- Turbulent temperature spectra measurements acquired in hot supersonic jets
- Complete Supersonic Aeroacoustic Database for axisymmetric jets; commence 3D database design.
- Apply DAMAS-C beamforming to shocked jets
- Design validation tests of offset stream concepts, plasma actuator
- System studies of Iconic Supersonic Vehicle



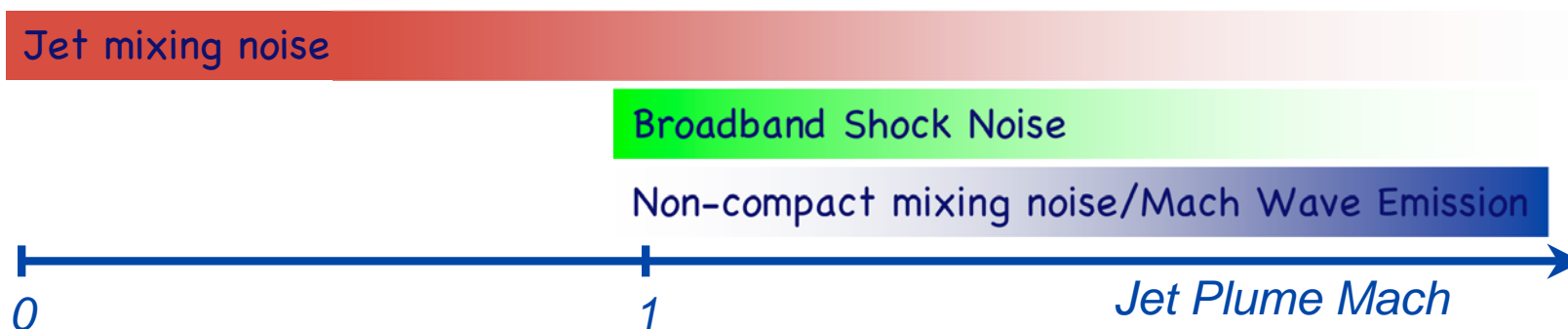
Supersonics Project: Airport Noise Session

- Prof. Philip J. Morris, “Efficient Prediction of Broadband Shock-Associated Noise: Modeling and Simulation”
- Dr. James Bridges, “Application of Time-Resolved PIV to Supersonic Hot Jets”
- Dr. Brenda Henderson, “Impact of Air Injection on Supersonic Jet Noise”



Jet Noise Source Nomenclature

Jet Noise Source Mechanisms That Prediction Codes Must Address:



Other factors:

- 3-D nozzles/plumes (modification of jet sources)
- Solid surfaces (new source types)
- Shielding/reflection/diffraction (complex inhomogeneous propagation)